DEVELOPMENT OF THE MIN-N FAMILY OF TRIANGULAR ANISOPARAMETRIC MINDLIN PLATE ELEMENTS

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Application of the finite element method to the bending of plates dates to the early 1960s. Nevertheless, the subject remains an active area of research because of the importance of plate structures and the difficulty to develop accurate and robust plate finite elements. During the past two decades interest in the shear deformable (Mindlin) plate theory has increased significantly, not the least because of the increased use of laminated composite materials. These types of structures usually exhibit much lower strength in the transverse direction and between the layer interfaces. Therefore, transverse shearing behavior can be significant in many cases. Consequently, the finite element method based on Mindlin theory can be a very effective tool to provide more accurate modeling of moderately thick and anisotropic (composite) plates with significant shear deformation. However, many formulations of Mindlin plate elements experience significant shear locking in the thin-plate regime. One of the more successful low-order Mindlin plate elements in the literature is Tessler and Hughes' MIN3 element [1], which is a 3-node triangle and avoids shear locking in the thin limit by using interpolation functions one degree higher for transverse displacements than for bending rotations, the so-called anisoparametric interpolation strategy.

A general formulation for a family of N-node, displacement-compatible, fully-integrated, pure-displacement, triangular Mindlin plate elements, MIN-N, is presented. The development of MIN-N has been motivated primarily by the success of the MIN3 element, which is the lowest member of the family. The family of MIN-N elements possesses complete, fully compatible kinematic fields, in which the interpolation functions for transverse displacement are one degree higher than the interpolation functions for rotations. In the thin limit, the elements satisfy the Kirchhoff constraints of zero transverse shear strains. General formulas for these constraints are developed.

As an example of a higher-order member, the 6-node, 18 degree-of-freedom element MIN6 is developed. MIN6 has a cubic variation of transverse displacement and quadratic variation of rotational displacements. The element, with its straightforward, pure-displacement formulation, is implemented in a finite element program and tested extensively. Numerical results for both isotropic and orthotropic materials show that MIN6 is competitive with SHELL93 (ANSYS) and MIN3 elements and exhibits good performance for both static and dynamic analyses in the linear, elastic regime. The results illustrate that the fully-integrated MIN6 element neither locks nor is excessively stiff in the thin limit, even for the coarse meshes.

References

[1] A. Tessler and T. J. R. Hughes, "A Three-Node Mindlin Plate Element with Improved Transverse Shear," *Computer Methods in Applied Mechanics and Engineering*, v. 50, p. 71-101, 1985.

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